Thesis/
Reports
Hasfurther,
V. R.

DEVELOPMENT OF CRITERIA TO CONTROL SEDIMENT DISCHARGES FROM RECREATION RELATED FOREST ROADS NEAR STREAMS

Victor R. Hasfurther

THESIS
AND
REPORTS
Hasfurther
C. 1

C. 1

Development of Criteria to Control Sediment Discharges from Recreation Related Forest Roads near Streams

by

Victor R. Hasfurther

Timothy R. Conner

Final Report

Cooperative Agreement No. 16-515-CA

Rocky Mountain Forest and Range
Experiment Station

CIVIL AND
ARCHITECTURAL
ENGINEERING

University of Wyoming, Laramie

LIBRARY

MAY 9 1977

ROCKY MOUNTAIN STATION

Development of Criteria to Control Sediment Discharges from Recreation Related Forest Roads near Streams

by

Victor R. Hasfurther

Timothy R. Conner

Final Report

Cooperative Agreement No. 16-515-CA
(EC #176)
Rocky Mountain Forest and Range
Experiment Station
Ft. Collins, Colorado

University of Wyoming
April 26, 1977

TABLE OF CONTENTS

	page
Chapter I. Scope and Purpose of Sedimentation Research	1
Introduction	1
Literature Review	3
Objectives of Study	4
Chapter II. Criteria and Methodology for Study of Processes Involved in Sediment Movement and Control Parameters	6
Road Characteristics Affecting Sediment Volume	6
Road Age	7
Road Gradient	10
Road Side Slopes	12
Soils Analysis of Cut, Fill and Roadway	16
Watershed Characteristics Affecting Sediment Volume as Independent Variables	17
Contributing Watershed Area	18
Direction of Side Hill Exposure	18
Buffer Zone Slope	19
Vegetative Cover and Downslope Obstructions	21
Dependent Watershed Variables in Analysis	22
Sediment Volume	23
Sediment Flow Distance	27
Chapter III. Study Areas and Site Selection Criteria	28
Pelton Creek Study Area	28
Encampment River Study Area	30

Site Selection Criteria 34
Data Information. 35
Chapter IV. Analysis and Results 39
Methods of Analysis 39
Results of Data Analysis 40
Chapter V. Applications and Conclusions 47
Application of Results 47
Conclusions 52
Selected References 54

FIGURES

page

Figure 1a. Cross-section of typical road prism 9

Figure 1b. Schematic view of a typical site showing road characteristics 9

Figure 2. Relationship between the road surface gradient and one inch rill cutting depth, from Packer 11

Figure 3. Photograph of a badly eroded cut slope at Test Site No. 26 14

Figure 4. Method used to determine the side slopes for both cut and fill slopes. 14

Figure 5. Method used to determine average buffer zone slopes. 20

Figure 6. Photograph showing logs normal to the direction of flow that have reached sediment trapping capacity . . 20

Figure 7. Typical sediment flow pattern and method used to determine sediment volume 24

Figure 8. Sampler tube used to determine the depth of sediment. 26

Figure 9. Pelton Creek study area 29

Figure 10. Encampment River study area 31

Figure 11. Percentage of sediment volume detained by first obstruction 41

Figure 12. Relationship between road gradient and accumulated sediment volume for roads of various ages 43

Figure 13. Relationship between buffer zone slope and sediment flow distance in feet for various numbers of obstructions 45

Figure 14. Sediment retention capacity of a 10 foot long log of various diameters 49

Figure 15. Sediment retention capacity of a 15 foot long log of various diameters 50

Figure 16. Profile of Solution to Example 1. 51

Figure 17. Profile of Solution to Example 2. 52

TABLES

page

Table I. Measured and computed data information for the sixty (60) study sites investigated 36

Chapter I

Scope and Purpose of Sedimentation Research

Introduction

In forested areas, a major source of stream pollution in the form of inorganic suspended solids are unpaved roads which cross or closely parallel streams (1, 2). These suspended solids are derived mainly by the exposure of the road surface and side slopes to the hydraulic action of rain or snow melt runoff after the stripping away of protective vegetation (3).

New roads constructed for use in forested areas can result in the pollution of streams below these roads by sediment movement from the road area (1). These roads are built prior or concurrent to a timber sales development. In most cases the road crosses or parallels streams thus increasing the potential for sediment movement downslope to a stream. After the area is harvested, many of the roads are then used as recreational or service roads continuing the possibilities for sediment movement and pollution.

This added sediment load due to the presence of a road can seriously degrade the quality of runoff water reaching a stream in many ways. Obviously, the problem of higher turbidity levels is certainly displeasing in light of esthetic considerations. The added turbidity can also affect the aquatic environment (4). The increased turbidity can sharply limit the amount of sunlight entering the stream and deplete dissolved oxygen levels due to the decreased photosynthesis

activity in algae and other aquatic plants since the photosynthesis process is driven by light energy. Also trout and other game fish which use vision to selectively feed, depend on clear water to sustain themselves. The microenvironment of the streambed may also be affected if even small amounts of inorganic sediment covers the streambed depriving the microenvironment of oxygen.

The stream structure may also change with time due to the addition of sediments. These structural changes are many and can include the formation of bars or scouring of the channel due to the increased abrasiveness of the flow creating even more sediment. Another problem that can occur is the increased rate of reservoir siltation downstream thus decreasing the useful life of a storage reservoir. Thus, it is apparent that sediment must be prevented from entering streams as much as possible in order to eliminate these problems and other similar problems.

Demand for lumber and related wood products is ever increasing as is the demand for higher water yields from watersheds. Recreational uses are also on the rise as more people visit the National Forests each year. The potential exists for even greater amounts of sediment to reach streams in the future which normally would not have previously existed.

This report will address itself to the problem of limiting the entrance of sediments to streams by various types of obstructions. Basically, the means by which sediments will be intercepted will be restricted to "the natural system," or the interception of sediments by resources already available in the forest.

Literature Review

A literature review is being included in this report to represent and summarize the most important previous investigations into the subject of controlling sediment movements into streams and channels. Various results and conclusions of these studies will be compared, when applicable, against the results of this study in the following sections.

Haupt conducted a study similar to this study in 1959 in which he related various road characteristics (road width, cross ditch spacing, road cut height, road gradient and embankment slope length) along with watershed characteristics (lower slope gradient, aspect of slope exposure and an obstruction factor) to the distance sediment would flow downslope. Using a multiple regression model, he developed design charts to aid in the placement of downslope obstructions (5, 6).

In 1967, Packer wrote a paper that went into considerably more detail than the previous Haupt study of 1959 (1). Packer related the same factors plus some additional ones that Haupt had previously neglected, to the distance it took to cut a 1-inch deep rill on the road surface. Packer related each factor, individually to the 1-inch rill depth distance. Packer also developed design charts to determine required cross drain spacing and distance to the first obstruction downslope for various conditions. Packer and Christensen later developed a handbook for use by engineers and technicians to determine, for various conditions, the proper cross drain spacing and protective strip interval between the roadway and the stream (3).

Megahan and Kidd in 1972 conducted a study in Idaho and showed that due to road construction in their study area, sediment production

increased an average of 770 times during the study period of six years. Most important, however, was that they determined that 85 percent of the erosion occurs during the first year after construction (7).

All studies agree that present methods of route location, road construction techniques and road maintenance can affect the amount of eroded soil material that is transported downslope and discharged into a stream. Roads located too close to streams as well as poor design criteria can contribute extensive amounts of sediment. Thus, sediment flow from roads are mainly influenced by road characteristics that are alterable through design (1).

Objectives of Study

It is the objective of this study to promote the understanding of sedimentation factors related to road design and the physical characteristics of the surrounding area. This study will mainly attempt to analyze the use of the "natural system" to control the deposition of eroded soil particles. The "natural system" used here means natural vegetation, fallen trees, tree stumps, rocks, branches and other debris, existing topographic features or any other natural feature which the sediment laden discharge must cross that retards the downslope motion of flow.

There are three main objectives of this study. The first objective is the evaluation of existing roads to determine factors which influence erosional processes and the subsequent deposition of sediments. In order to effectively define the variables for data collection and to determine the relative importance of each variable, these factors must be known.

The second objective is to determine the effectiveness of existing methods of controlling sediment movement. Since no methods of controlling sediment movement have been employed in the Medicine Bow National Forest where this study was conducted, this objective will be limited to examining the natural system in which natural conditions have aided in retarding the movement of significant amounts of sediment.

The third objective is to develop criteria to control sediment movements on new and existing forest roads where the possibility exists of sediments entering a stream. The criteria to be developed will be used as a means for locating drainage culverts to optimize the use of existing topographic and other downslope conditions which would cause sediment to be deposited downslope from the road rather than entering a stream. If relocating the culvert is impractical, criteria will be developed as to the actual placement of obstructions downslope of the road. The criteria should also provide information to install some sort of sediment control and to evaluate the effectiveness of present downslope obstructions on older roads to determine whether more protection is required.

It is also the goal of this study that the criteria developed herein will be usable in other regions of the country. It is expected that the methods and criteria of this study can be applied to most forest roads in regions that have similar soil, relief and vegetative characteristics.

Chapter II

Criteria and Methodology for Study of Processes Involved in Sediment Movement and Control Parameters Used and Quantities Measured

The determination of parameters to be measured and data to be collected resulted from an intensive investigation of pertinent literature which indicated the most important factors influencing the rate of sedimentation and sediment movement. However, time and financial limitations eliminated some of the parameters that the literature indicated were important and could have been measured or taken into consideration.

The parameters that were used in the study and actually measured or determined will be explained in detail in the following subsections. Each of these parameters at each site was determined by some measurement and recorded. The first five subsections concern independent variables which are related to roadway characteristics. The next four subsections concern independent variables that are watershed characteristics. The last two subsections, sediment volume and sediment flow distance, will be treated as a dependent variable with respect to roadway and watershed characteristics.

Road Characteristics Affecting Sediment Volume

Road characteristics have a definite effect on the volume of sediment that is derived from the roadway. The road characteristics mentioned in this section may or may not be alterable through design.

However, understanding how these road characteristics affect the sediment volume can be helpful in controlling sediment movement.

Road Age

The age of a road is defined in this paper as the time in years since the road was completed. The age of a particular road section under investigation plays an important part in the sedimentation process. It was pointed out in Chapter I that 85 percent of the sediment deposited below a roadway will be trapped there during the first year after construction. Packer (1) showed that the ability of logs normal to flow to trap sediment remains fairly constant over the first three or four years after construction. The ability to trap sediment will decrease to zero as the sediment covers the obstruction and flows downslope.

The actual variation in the ability of obstructions to trap sediment with respect to time is unknown. In the field study, sites were stratified by age in an attempt to show this variation of obstruction efficiency with respect to time as well as to show the rate of sedimentation with respect to time. The ages of the roads used in this study were obtained through written communication with Medicine Bow Forest Service personnel (8).

Contributing Road Surface Area

The contributing road surface area is defined as the sum of the areas that have the natural vegetation and topsoil removed and contribute runoff to the inlet of a drainage culvert. This area consists of the roadway surface area sloped to the drainage ditches, the cut slope

area and the drainage ditch area. The above definition does not include the fill slope area because runoff is not concentrated and conducted to the culvert inlet from the fill slope. The runoff from the fill slope surface does cause serious erosional damage to unstable embankments of loose soil material. These sediments, however, usually extend only two to ten feet downslope from the toe of the fill slope and in most cases pose little or no great sediment pollution problem. Using the notation given in Equation 2.1 and the geometry of the roadway cross section shown in Figure 1a and 1b, the contributing road surface area may be expressed mathematically as:

$$Ar = (W_d + W_r + W_c)L/43560 \qquad (2\text{-}1)$$

Where Ar = contributing road surface area in acres

W_d = width of the ditch sloping from the inner road surface edge to the toe of the cut slope in feet

W_r = width of the roadway running surface in feet

W_c = average width of the cut slope in feet

L = length from discharge culvert to an upslope culvert or drainage divide in feet.

Since at any point along the length of test section, L, the width of cut slope may vary, an average width is determined and is used in representing a uniform road cross section and it is assumed that the runoff is uniform over the entire area.

The terms of Equation (2-1) with the exception of L, were measured in the field using a woven cloth tape. Once the typical cross section was chosen for a particular site, the width of the cut, ditch and

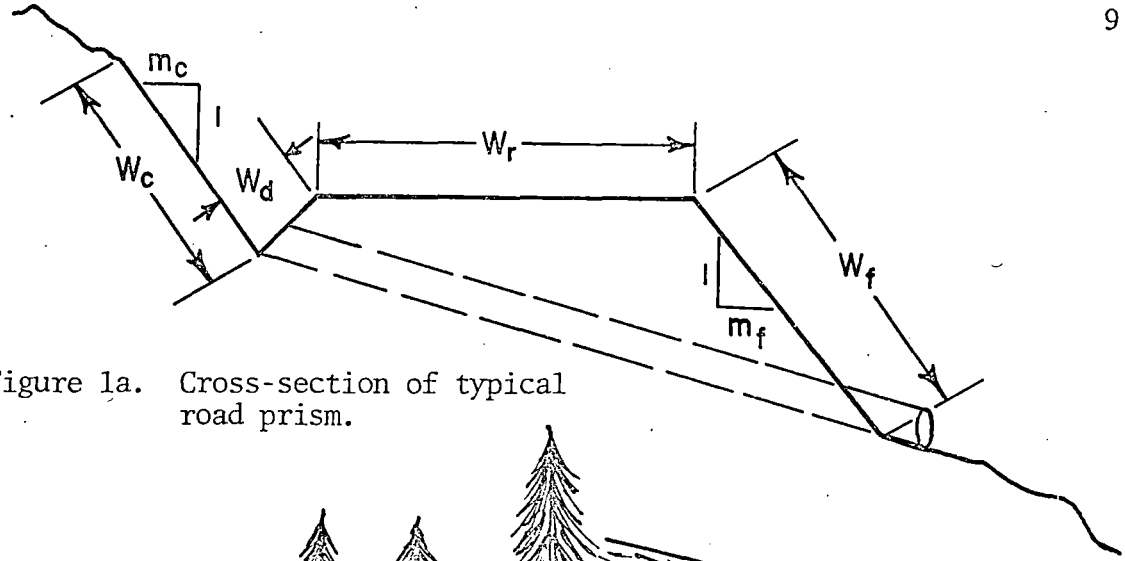


Figure 1a. Cross-section of typical road prism.

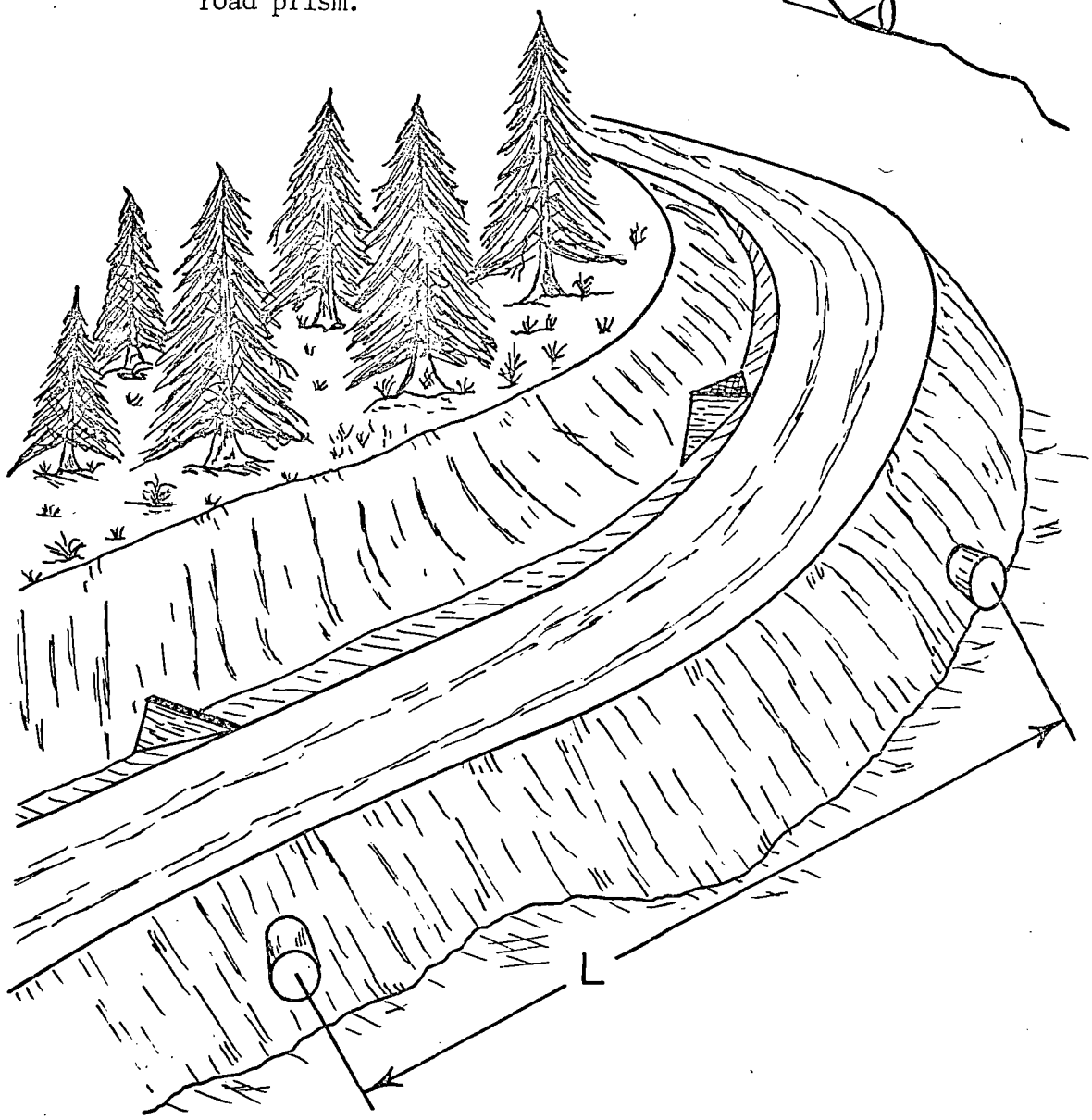


Figure 1b. Schematic view of a typical site showing road characteristics.

roadway surface was measured on the slope to the nearest foot (the fill slope width, W_f, was also measured for possible use in future studies). The length between drainage structures or drainage structure and a drainage divide was obtained from detailed road profiles that were furnished by the United States Forest Service.

Road Gradient.

The road gradient has a very large influence upon the erosion of the roadway surface and transport of the eroded material. Packer (1), related road gradient to the distance it takes water flowing over the roadway surface to cut a rill one inch deep. This relationship is shown in Figure 2. The erosive cutting distance is infinite when the road gradient is zero percent. As the road gradient is increased, the erosive cutting distance becomes finite and then decreases rapidly as the road gradient steepens.

This relationship indicates that the cutting power, and thus the potential for more serious erosion, increases with road gradient. The reason for the additional cutting power is due to the increased runoff velocity imparted by this increase in road gradient. The increase in runoff velocity will also give the fluid a greater ability to transport the sediment downslope.

The average road gradient at a particular site was acquired by examination of detailed road profiles that were furnished by the U.S. Forest Service. The average road gradient is the ratio of road surface drop in feet to the distance between an upslope drainage structure and the culvert in question in feet, multiplied by 100 percent.

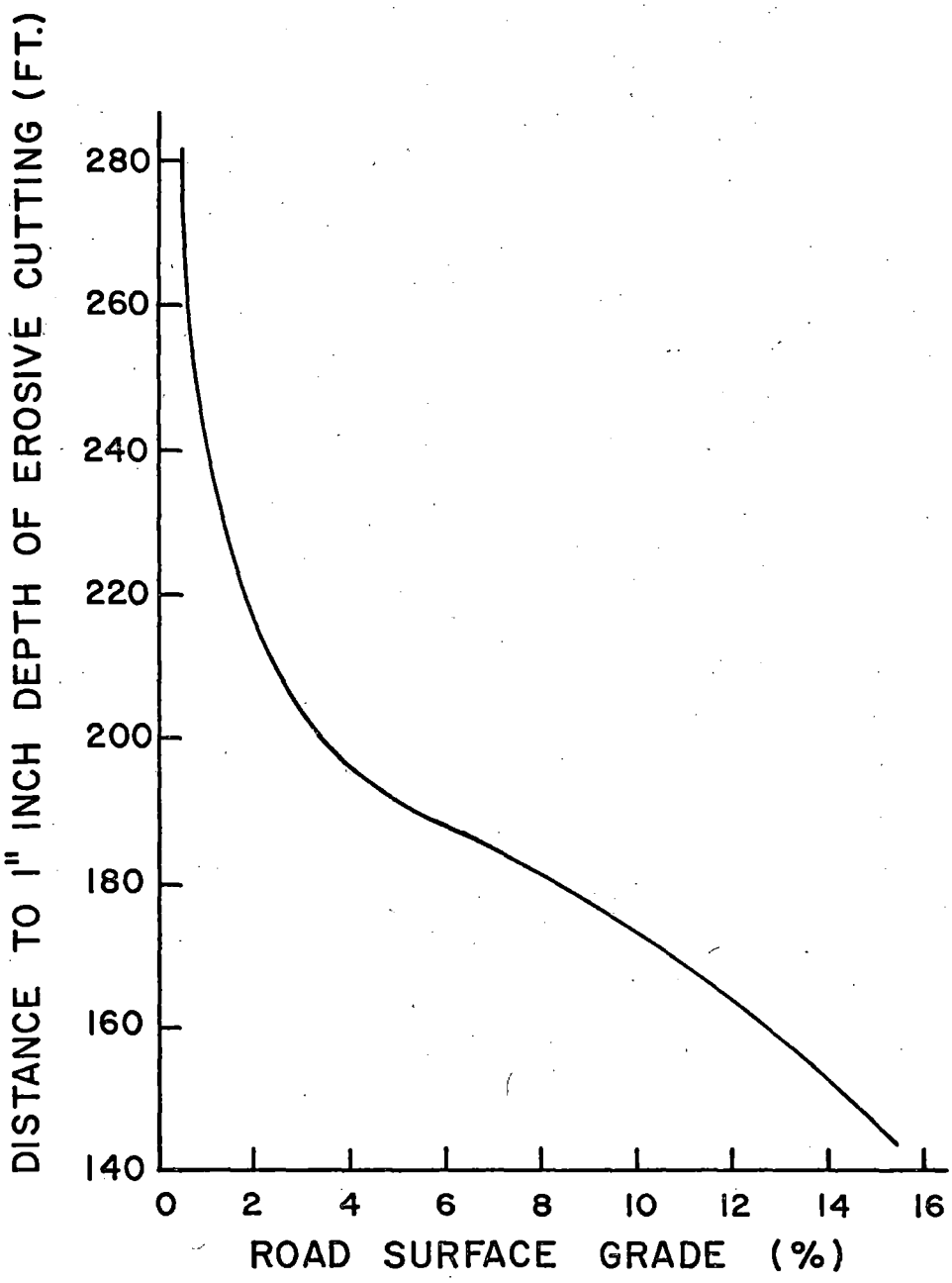


Figure 2. Relationship between the road surface gradient and one inch rill cutting depth, from Packer (1).

Road Side Slopes.

The side slopes of a road are a major source for possible sediment yield. As runoff from the undisturbed upper slope intersects the top of the cut slope, the slope gradient is increased imparting a greater velocity gradient to the runoff as it moves over the cut slope.

This situation can be very serious, especially during the first year after construction. After construction, the cut slope is bare and very susceptible to erosion until vegetation takes root and grows enough to provide stability for the cut slope. However, in some instances the runoff can actually erode away young plants and seeds. The best way to reduce the sediments derived from the cut slope surface is to restabilize the cut slope by planting hardy, fast-growing grasses on the slope as soon as possible after completion of construction (9).

A distinction is made between erosional processes. The erosion of the road surface and the cut slope surface is mainly sheet erosion. Sheet erosion is erosion caused by sheet runoff or that part of rainfall or snowmelt runoff that is not infiltrated into the soil, evaporated or detained by vegetation, depressions or other obstructions. This runoff, or overland flow, is capable of eroding significant amounts of loose soil material.

The sheet runoff may eventually combine with other portions of overland flow and become concentrated in rills, rivulets, small streams or rivers. This combined flow is now concentrated in a channel and may be termed channel runoff. Channel runoff is usually more destructive in terms of erosive cutting power because of higher velocities of the concentrated flow.

Material derived from the upper undisturbed slope and the cut slope is transported to the foot of the cut slope (the ditch bottom) via overland and rill flow. This material can be deposited in the ditch or transported through the culvert. The deposition or transportation of eroded particles in the side ditch depends mainly upon the flowrate and the slope of the side ditch. If the material is deposited in the ditch, as very often happens in the case of snowmelt runoff and summer showers, the ditch rapidly fills with sediment. Also, sediment can be derived from the roadway surface since the roadway surface is insloped toward the ditch to prevent ponding of water on the road surface (Figure 1a). If sediment is deposited in the ditch, future rainfalls of a very intense nature or long duration can erode the unconsolidated deposits of sediment and transport this sediment through the culvert and on downslope.

A badly eroded cut slope is shown in Figure 3. Elements of the erosional process can be seen in this photograph. Loose soil has been stripped away by overland flow and larger gravel particles are left on the slope. Also, deep rills have been formed on this very short section (20 feet) of cut slope. It is also interesting to note the relatively undisturbed state of the upper natural slope in the extreme top of the photo. Little or no erosion can be seen at the top of the photo due to the vegetative cover and lesser slope.

The fill slope of a road can contribute substantial amounts of sediment in excess of the cut slope sediment yield. Megahan points out that in one study the surface erosion on fill slopes was approximately 1.75 times that on a road cut slope (9). This is primarily

Figure 3. Photograph of a badly eroded cut slope at Test Site No. 26 (W_c = 20 feet, m_c = 3:1).

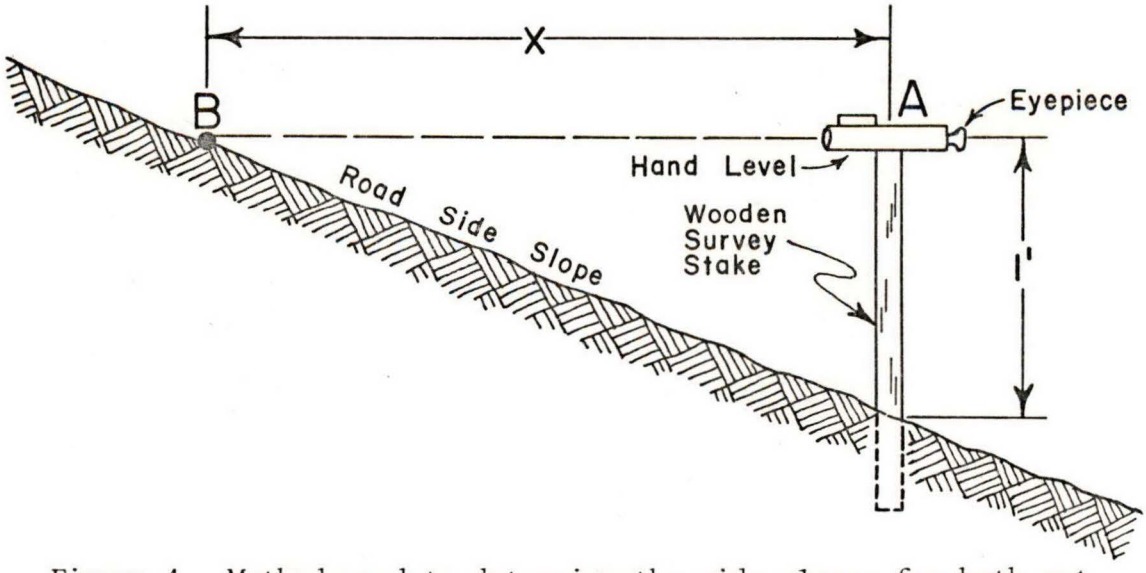


Figure 4. Method used to determine the side slopes for both cut and fill slopes.

due to the lesser consolidation of soil material in the fill section. The fill slope soil is placed and mechanically compacted, whereas the cut slope soil is scraped off and the exposed soil exists under naturally compacted conditions.

Fill slopes are often subject to mass wasting, another type of erosional process. Mass wasting can be defined as a bulk transfer of masses of rock or soil material down slopes under the influence of gravity (10). Mass wasting is broken down into several categories based on the speed of mass movement. Usually, the type of mass wasting observed on road fill slopes has been a relatively slow process preceeded by saturation of the soil mass. The slump of the fill slope is influenced by antecedent soil moisture, type of soil, and loading conditions. Insloping of the road surface toward the ditch allows water to be drained from the road surface and reduces the amount of water allowed to flow over the fill slope surface.

The fill slope will not be incorporated into this study since sediment derived from the fill slope is usually deposited along the toe of the fill slope. The sediment that is deposited here is usually not a problem to pollution of the downslope environment. The main problem that makes itself immediately apparent is the damage to the stability of the road due to the back cutting of the fill slope.

The cut slope and the fill slope were measured by use of a hand level. A wooden surveying stake was driven vertically into the side slope so that one foot of stake protrudes above the slope surface as shown in Figure 4. Once the stake is placed, the hand level is placed at the one-foot level at point A. The viewer then looks through the

eye piece and centers the floating bubble about the center line at the end of the hand level barrel. When the bubble is centered, the line of sight projected concurrent to the center line is a horizontal projection (11). The horizontal line is projected from point A to point B the intersection with the side slope surface. Point B is marked and the horizontal distance x is measured to the nearest one-tenth of a foot. The side slopes may be defined as the horizontal change in feet per one foot vertical change in elevation. Also, the angle θ that the side slope makes with the horizontal may be determined from equation (2-2).

$$\theta = \tan^{-1} \left(\frac{1}{x}\right) \qquad (2\text{-}2)$$

Soils Analysis of Cut, Fill and Roadway.

Intuitively, one of the major factors in determining the erodability of a certain road section is the type of soil the road is built through. Packer showed in his study the relationship between soil aggregate size and the change in distance to the one-inch depth caused by erosive cutting action (1). This relationship shows that the cutting distance on the roadway surface decreases as the percentage of water stable aggregates larger than two millimeters (approximately 0.08") in diameter decreases. This means that the greater the amount of coarse material, the less likely the material will be eroded away under normal circumstances. Increasing the aggregate size is easily accomplished on the roadway surface by graveling, which also serves to improve the running surface of the road.

Packer also points out that the soil particle shape could also affect the resistance the soil particle offers to movement. Highly

irregular, angular shaped particles offer a greater resistance to movement than do rounded, weathered particles because of the loss of interlocking between adjacent particles. However, neither the Packer study or this study will include particle shape as a parameter in the final analysis. Particle shape is not included since it is not easily quantified or alterable through design as is particle size.

Cut, fill and roadway surfaces were analyzed to determine soil size distribution. Soil samples were obtained from the cut slope, the fill slope and the roadway surface by removing approximately one inch of soil from the top of each surface in a representative section for that site. Each soil sample was typically 10 to 20 pounds. The samples were allowed to dry and a mechanical grain size analysis was performed in the Soil Mechanics Laboratory at the University of Wyoming's Department of Civil Engineering. The grain size analysis was performed by use of a series of U.S. Bureau of Standards sieves. The sieves that were used in the soil particle size distribution analysis were the 1½ inch, 1 inch, ½ inch, #4, #10, #40, and #200 U.S. Bureau of Standards sieve series (12).

Watershed Characteristics Affecting Sediment Volume as Independent Variables

In addition to road characteristics, watershed characteristics can affect the volume of sediment derived from a roadway. These characteristics are those of the undisturbed areas surrounding the roadway that act to increase or decrease sediment movement.

Contributing Watershed Area

The contributing watershed area, excluding the road surface area, is that area on which precipitation falls and the subsequent runoff is channeled by overload flow, rills, rivulets and small channels to a discharge culvert which drains runoff under and across the road section. Topographic features of the surrounding area determine the boundaries and the outline of the contributing area. Depressions and other areas from which water is diverted elsewhere which do not contribute water to the inlet of the road culvert were deducted from the total area to arrive at the corrected acreage for the contributing watershed area.

The contributing area was determined by first locating the test site drainage culvert on a detailed topographic map and sketching the approximate contributing drainage area that conducts runoff to that culvert. This area was then planimetered and the area was obtained in square feet. However, for convenience, the area in square feet was converted to acres.

Direction of Side Hill Exposure

The direction of exposure of the side hill on which a road is built is also an important variable which must be taken into consideration. Roads built on slopes of north facing fills are usually less susceptible to erosion than roads that are built on hills having a south facing exposure (3). The reason for this lies in the movement of the sun relative to the hill. Slopes which face south receive more direct exposure to the sun, thus causing a faster melting of the snowpack and greater weathering of the soil material. Since the snowmelt

is faster, the runoff is distributed over a shorter period of time, thus having a potential for greater erosion. This can also cause south facing slopes to have less vegetative cover to retard the flow of surface runoff and as a result increases the erosive cutting power of the runoff. The relative vegetative density usually decreases in the following order for directions of side hill exposure: north, east, west and south (6). The ability to resist erosion is directly proportional to the vegetative density and will decrease as vegetative density decreases.

The direction of side slope exposure for a particular test site was obtained from a detailed topographic map on which the test site had been located. The direction of exposure will be noted as either north, south, east or west.

Buffer Zone Slope

The buffer zone slope is the natural slope of the hillside below the toe of the fill slope. The buffer zone slope is similar to the road cut and fill slopes in the manner in which it influences the velocity of runoff water discharging down its face. The buffer zone slope is important because it will also affect the length of sediment flow path. This statement is made for the present without respect to downslope obstructions and vegetation on the buffer zone slope which intersects the sediment flow path.

The average buffer zone slope was measured in a manner similar to the measurement of the cut and fill slopes. A wooden surveying stake is set in the slope so that one foot of stake is protruding from the ground as shown in Figure 5. This stake, as before, is used as a

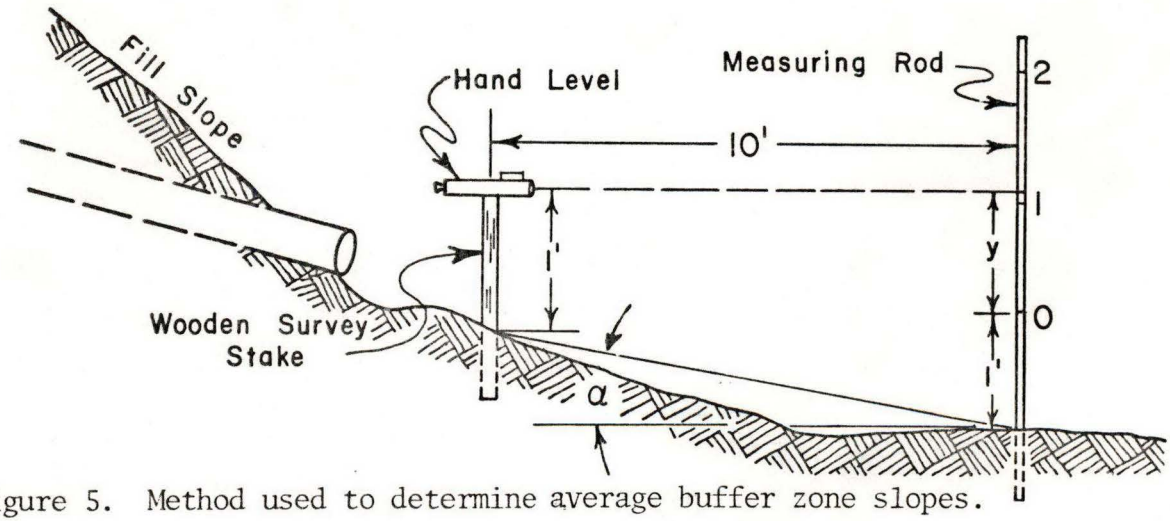


Figure 5. Method used to determine average buffer zone slopes.

Figure 6. Photograph showing logs normal to the direction of flow that have reached sediment trapping capacity (Test Site No. 30).

reference datum and as a support for the hand level. A premarked measuring rod, ruled in tenths of a foot, was placed 10', horizontal distance, from the wooden surveying stake. It is placed so that there is one foot between the zero mark on the measuring rod and the ground surface to offset the one foot above the ground on which the hand level is placed. A horizontal line is sighted through the hand level and the corresponding rod reading, y, on the measuring rod is recorded to the nearest tenth of a foot. The slope of the buffer zone, α, can be computed by equation (2-3).

$$\alpha = \tan^{-1} \left(\frac{Y}{10}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}3)$$

This buffer zone slope is not usually constant for the entire sediment flow path length. The slope that was measured is the slope immediately downslope of the discharge culvert since this portion of the buffer zone slope has the most influence on the sediment flow path length.

Vegetative Cover and Downslope Obstructions

Vegetative cover and downslope obstructions play a very important role in detaining and retarding flow downslope. Any obstruction that offers resistance against the downslope flow from a culvert will cause a dissipation of fluid energy. As the resistance to flow increases, sufficient fluid energy is dissipated so that the fluid can no longer suspend the sediment and the particles settle out of solution.

Different obstructions are less effective than others in their ability to retard the downslope movement of sediment. Packer (1)

has listed the effectiveness of various obstructions in the following order of descending effectiveness:

1. Mounds and depressions,
2. Fallen logs normal to the flow,
3. Rocks,
4. Standing trees and stumps,
5. Slash and brush,
6. Herbaceous vegetation.

The effectiveness of these various obstructions is also dependent upon time. For example, logs placed normal to the sediment path lose capacity to return sediment with time. This can be seen in Figure 6. Figure 6 shows a log which has fallen normal to the direction of flow being discharged from a culvert. It can be seen that the log has done an excellent job of stopping sediment movement downslope. However, the capacity of the log to stop sediment movement is now seriously limited and sediment flows over the log and is deposited downslope.

The type of obstruction or obstructions were noted at each test site. Also, the size and spacing of obstructions was also recorded. Herbaceous vegetation was also recorded as to type and an estimate of vegetal cover density was also estimated. Photographs were taken at each site to record the effectiveness and type of obstruction.

Dependent Watershed Variables in Analysis

The nine variables just discussed which refer to roadway and watershed characteristics will be independent variables used in a multiple regression model related to the dependent variables sediment volume and sediment flow distance. Both dependent variables were

measured at each test site. The next two subsections describe the method used to determine each dependent variable.

Sediment Volume

The sediment volume at each site was estimated in order to relate road and watershed characteristics to the volume of sediment deposited on the buffer zone below a section of road. The volume of sediment depends upon the road and watershed characteristics previously described which gives a good description of the actual processes involved.

The procedure used to estimate the volume of sediment that has been deposited below a road section via a culvert is discussed below and shown in Figure 7. A wooden surveying stake is set at point A, the center line of the discharge end of the culvert. A line is tied to this stake and extended to the end of the sediment flow, point B, where it is tied to another stake that also coincides with the centerline of the longitudinal axis of the culvert. This line is represented by line $\overline{AB}$ in Figure 7 and serves as a datum for further measurements. The length $\overline{AB}$ is then divided into an even number, 2m equal parts by means of 2m + 1 points, each h distance apart. At each of the 2m + 1 points a line perpendicular to line $\overline{AB}$ is extended across the sediment path on both sides of line $\overline{AB}$. One of these lines is represented as line $\overline{CD}$ on Figure 7. A string is stretched along line $\overline{CD}$ and tied to stakes set outside the sediment path. Line $\overline{CD}$ is then divided into an even number of parts (2n) by 2n + 1 points each s distance apart represented by the filled in dots on Figure 7.

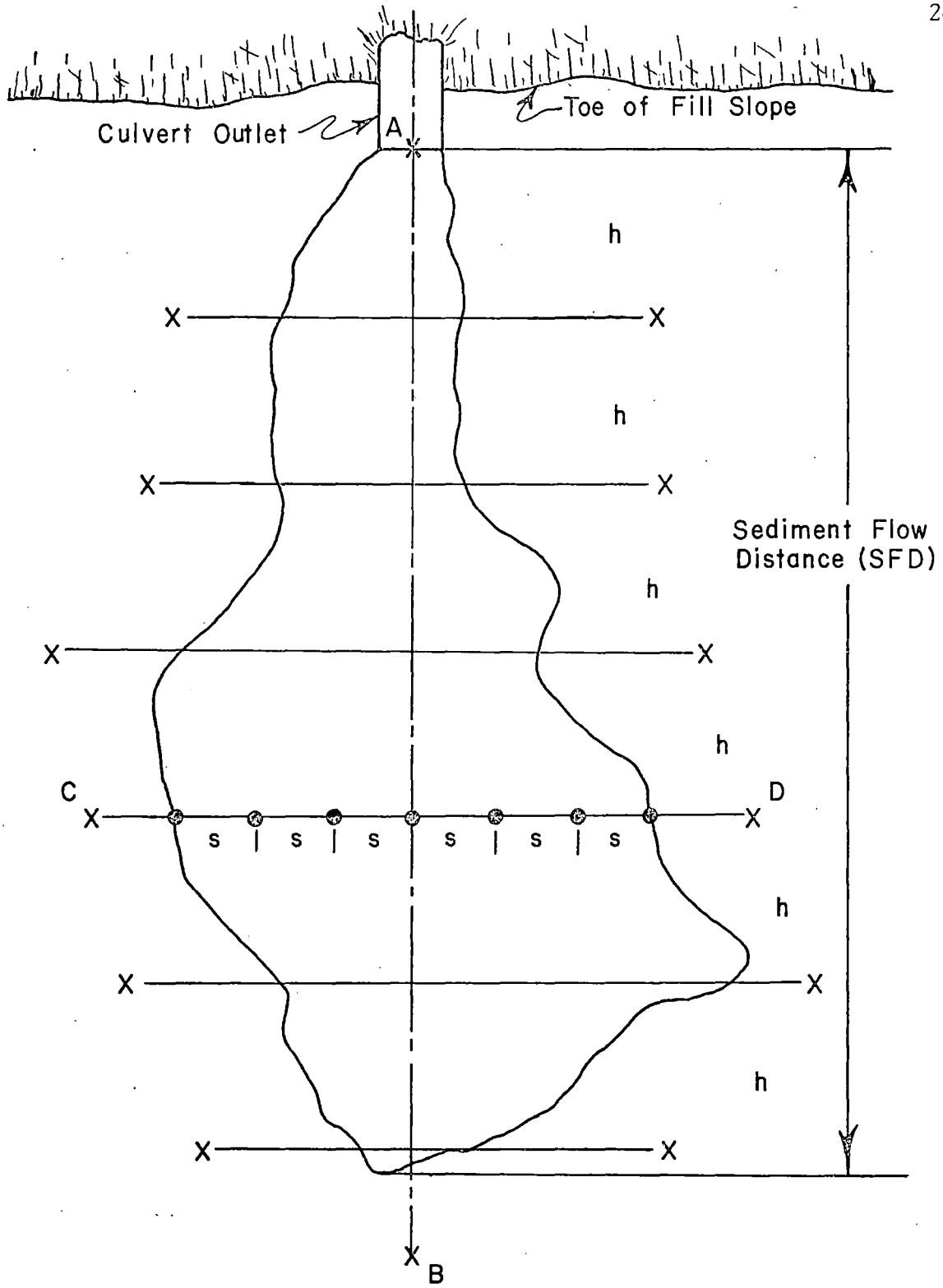


Figure 7. Typical sediment flow pattern and method used to determine sediment volume.

At each point on line $\overline{CD}$, the depth of sediment is measured to the nearest tenth of an inch thus yielding a sediment cross section at each of the 2m + 1 lines along line $\overline{AB}$. Depths of sediment were measured by use of a thin wall aluminum tube with a beveled end. The sampler tube is shown in Figure 8.

The sampler tube is slowly rotated while driven into the sediment at each point along the 2m + 1 panels by a slight pressure applied vertically by the hand. The sampler tube is inserted into the ground until the experimenter can feel a change in texture while the sampler tube is being rotated. The sampler tube is then withdrawn carefully and the depth of sediment is then measured. The change in texture felt when the tube is driven into the ground results from a change in soil materials. When the tube is extracted, a small amount of different soil material holds the unconsolidated sediment in the tube as shown in Figure 8b.

A sediment cross section was found for each of the 2m + 1 lines at each test site. The sediment volume was determined by Simpson's Rule for Irregular Areas (13). The area for each cross section was first found using equation (2-4):

$$A = \frac{1}{3}s\,[(d_o + d_{2n}) + 4(d_1 + d_3 + \cdots + d_{2n-1}) + 2\,(d_2 + d_4 + \cdots + d_{2n-2})] \quad \ldots\ldots\ldots \quad (2\text{-}4)$$

where: A = cross sectional area (square feet);

s = distance to sediment depth measurements (feet);

and d = depth of sediment (feet).

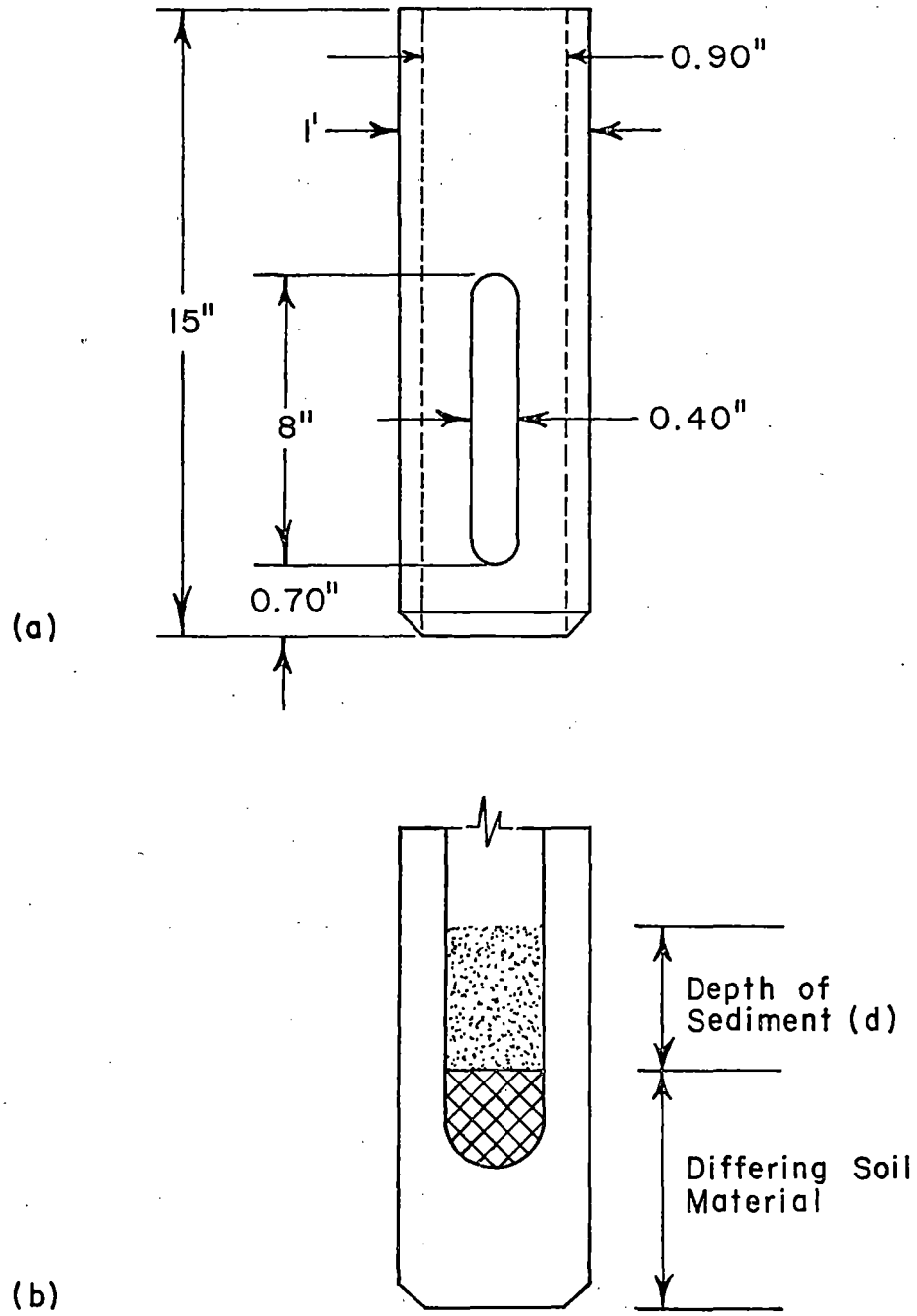


Figure 8. Sampler tube used to determine the depth of sediment.

The sediment volume can also be determined using Simpson's Rule. The sediment volume at each cross section was determined using equation (2-5):

$$V = \frac{1}{3} h \left[(A_o + A_{2m}) + 4(A_1 + A_3 + \cdots + A_{2m-1}) + 2(A_2 + A_4 + \cdots + A_{2m-2}) \right] \quad \ldots\ldots\ldots \quad (2\text{-}5)$$

where: V = sediment volume (cubic feet);

h = distance between cross section (feet);

and A = sediment area for 2m + 1 cross sections (square feet).

Sediment Flow Distance

The distance downslope that sediment flows is a very important consideration of this study. If this distance can be minimized, the amount of sediment reaching a stream can be reduced. The sediment flow distance is very dependent upon conditions downslope of the discharge culvert. This may include buffer zone slope, number of obstructions, type of obstruction, and flowrate through the culvert, just to name a few.

The sediment flow distance was measured at the time the sediment cross sections were determined. The sediment flow distance, as shown in Figure 7, was measured with a woven cloth tape to the nearest foot.

Chapter III

Study Areas and Site Selection Criteria

Pelton Creek Study Area

The Pelton Creek study area is located on the Wyoming-Colorado border in south central Wyoming about 45 miles west of Laramie, Wyoming. The Pelton Creek study area is shown on Figure 9. The soils for the Pelton Creek area are weathered from igneous and metamorphic bedrock. The main overstory vegetation is Lodgepole Pine with some Aspen trees. The understory is mainly vaccinium, grasses and shrubs. The area has an annual precipitation of between 30 and 40 inches, mainly in the form of snowfall. Most of the area is above 8,000 feet elevation.

Pelton Creek Road. The area of particular interest for this study is in the immediate vicinity of Pelton Creek. Pelton Creek road parallels Pelton Creek for about five miles. At some points the centerline of the Pelton Creek road is only approximately 150 feet or less from Pelton Creek.

Pelton Creek Road is about seven miles long and has a graveled roadway surface. The road was completed in 1974 and is very well traveled in the summer. Erosion of the fill slopes has been a problem on this road over the past two summers from on site observations.

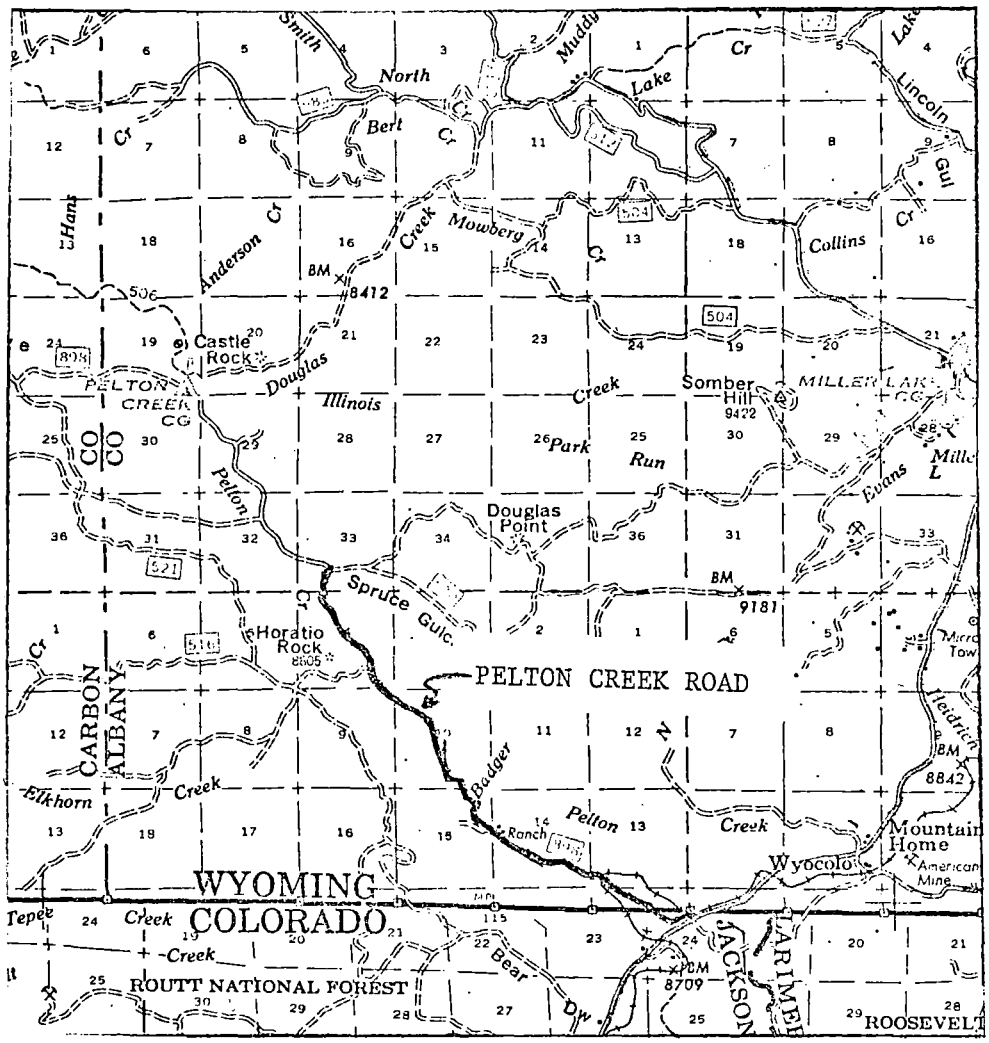


Figure 9. Pelton Creek Study Area.

Encampment River Study Area

The Encampment River study area is located on the Colorado-Wyoming border, about 15 miles south of Encampment, Wyoming. The Encampment River study area is shown on Figure 10. The soils in this area are mainly derived from igneous and metamorphic bedrock. The vegetation and soil conditions are diverse and will be discussed in more detail in the following subsections.

Medicine Bow National Forest Service personnel indicated that this particular area would prove a very appropriate area for this study. The Encampment River watershed in Colorado and Wyoming has had detailed studies conducted in relation to soils, geology, vegetation, land use, etc. Also, various hydrologic and meteorological studies have been conducted on this watershed. The annual precipitation ranges from 28 to 46 inches. The description of this study area was obtained from ecosystem maps and detailed statistics compiled by the Forest Service for the Encampment River Planning Unit (14).

Rim Road. The Rim Road is broken down into three sections. In 1974 the Rim Road was essentially rebuilt from the Colorado State line northeast for about nine miles. The remainder of this portion of the Rim Road (about five miles) was completed in 1968.

The soils on which this portion of road was built was medium to coarse textured soils derived from igneous and metamorphic bedrock. The overstory vegetation is mainly Lodgepole pine with an understory of vaccinium and intermittent patches of grass near streams. Erosion

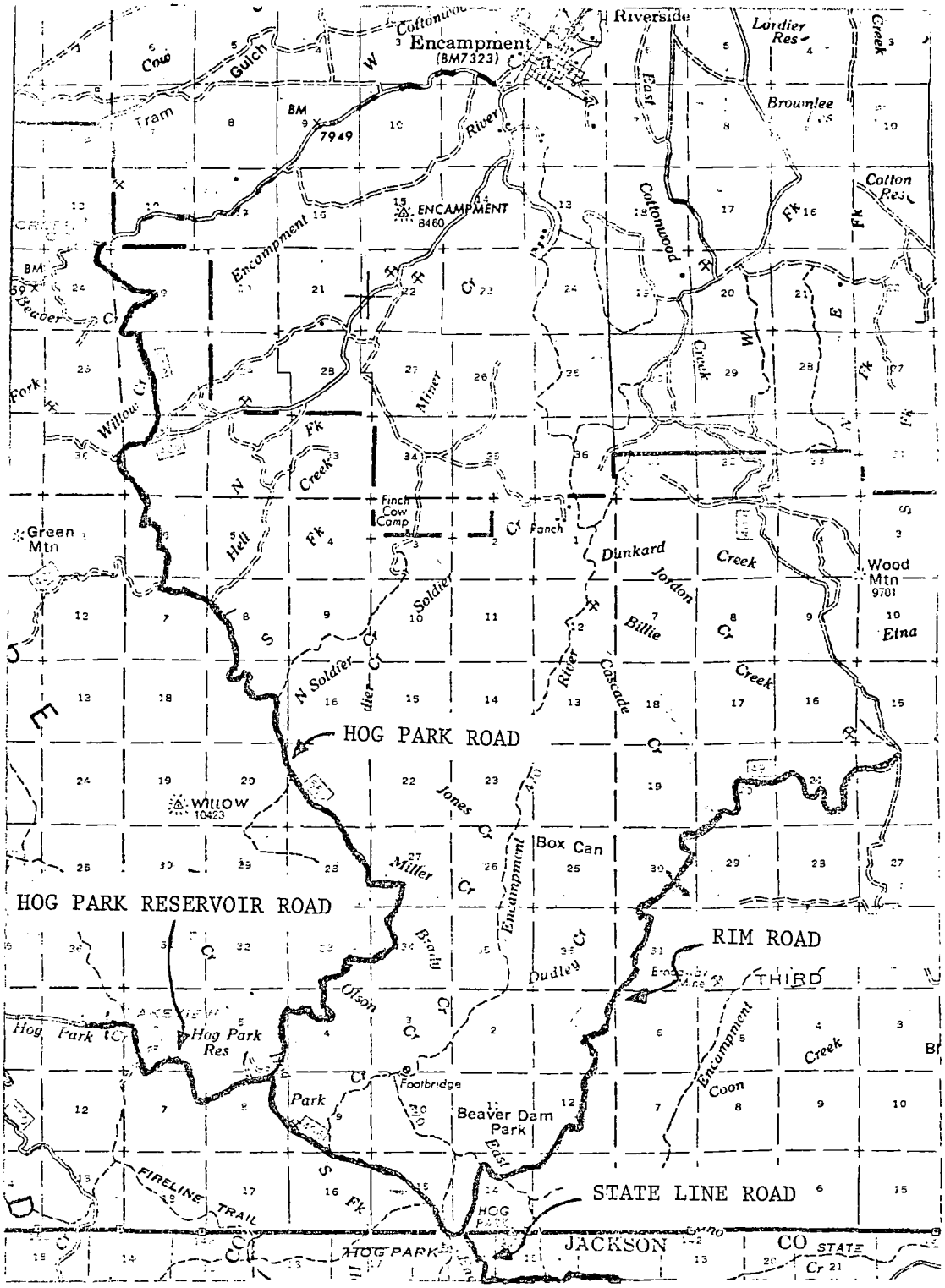


Figure 10. Encampment River Study Area.

potential of soils on this road is fairly high. Fill slopes on the new portion of the Rim Road has experienced serious erosion and some mass wasting in several locations along the road.

A third portion of the Rim Road was completed in 1972. This portion of the Rim Road extends northwest from the Colorado State line to the Hog Park Road-Hog Park Reservoir Road junction. The southern portion of this section is located in an area with dense lodgepole pine overstory and an understory of vaccinium. The middle portion of this road has an overstory of Engelman spruce and subalpine fir trees with an understory of vaccinium. The soils in the southern and middle portion of this section of the Rim Road are deep, coarse to medium textured soils developed during glacial deposits. The northern portion of this road is built on deep soils developed from material weathered from igneous and metamorphic bedrock. The main vegetation is sage brush and tall, dense grass. The potential for erosion in these areas is high.

State Line Road. The State Line Road closely parallels the Wyoming-Colorado State Line for several miles. The road is located in the Routt National Forest in northern Colorado. The State Line Road was completed in 1972 and handles fairly heavy traffic during the summer. Approximately eight miles of the State Line Road were studied in this report. This portion of the State Line Road was built on soils derived from material weathered from igneous and metamorphic bedrock with a high erosion potential. The overstory vegetation is mainly lodgepole pine with an understory of vaccinium and grasses near streams.

Hog Park Reservoir Road. Hog Park Reservoir Road is a newly graveled road (finished in 1974) that closely follows the perimeter of Hog Park Reservoir. This road is heavily traveled during the summer months due to recreation related traffic going to Hog Park Reservoir. About four miles of road were studied in the perimeter of Hog Park Reservoir. The Hog Park Reservoir Road was built on deep soils that were formed by alluvial deposits and some soil developed from the weathering of igneous and metamorphic rock. These soils have a moderate to high erosion potential. The main vegetative types are sagebrush, sedge, willows and grasses.

Hog Park Road. The Hog Park Road was separated into three parts, Hog Park Road South, Hog Park Road Middle, and Hog Park Road North. Hog Park Road South is 1.9 miles north from the Hog Park Reservoir - Rim Road junction and was completed in 1966. Hog Park Road Middle continues north for another 11 miles and was completed in 1968. These two sections of the Hog Park Road were built on soils derived from weathered granite. The main overstory vegetation are Engelman spruce and subalpine fir with an understory of vaccinium, grasses and forbs.

Hog Park Road North extends further north from Hog Park Road Middle for another 3.9 miles. This section of road was completed to the Battle Highway in 1968. The soils in this section were derived from igneous and metamorphic bedrock. The main overstory vegetation is lodgepole pine with an understory of vaccinium and some grasses.

Site Selection Criteria

Sixty (60) study sites were selected for sedimentation analysis and the parameters outlined in Chapter II were determined for each site. To fulfill the objectives of this study, the sites were chosen conforming to the following criteria:

1. Drainage structures on existing road must be immediately above and below the road section chosen so that all surface runoff and eroded soil originating on the road section is diverted to the study area below the road without allowing any discharge to continue on down the road. Natural topographic drainage divides were considered to be part of a set of drainage structures.
2. Groups of roads of different ages (the age differences should indicate time dependency of the sediment movement) were chosen having the same physical characteristics of :
   a. Road grade,
   b. Soil classification,
   c. Direction of exposure,
   d. Surrounding vegetation, and
   e. Topographic position.

Data Information

A large amount of the reduced field data for the sixty (60) study sites determined or measured from the field study during the summer of 1975 are displayed in Table 1 with the road and road station number indicated. The road station number is from plans furnished by the Medicine Bow National Forest Engineering Division. The data conforms to information on methodology presented in Chapter II.

TABLE I

Measured and Computed Data Information for the Sixty (60) Study Sites Investigated

Site	No.	Station	Side Hill Exposure	% Road Gradient	% Buffer Zone Slope	Road Age (yrs)	Road Surface Area (Acre)	Watershed Area (Acre)	Sediment Flow Dist. (ft)	Sediment Volume (ft^3)	Number of Obstructions
	1	21 + 49.6	N	6.0	16.7	2	0.78	54	13	4.87	3
	2	42 + 82.5	N	2.2	16.7	2	0.68	29	75	29.1	6
	3	51 + 81.8	N	3.2	5.6	2	0.78	8	8	11.6	3
	4	62 + 45.7	W	0.5	6.7	2	0.49	14	9	5.1	1
Pelton	5	85 + 64.6	W	4.2	23.8	2	0.91	30	9	9.8	3
Creek	6	93 + 50	W	5.0	0.0	2	0.97	20	8	21.7	3
Road	7	277 + 57.1	N	2.6	0.0	2	0.75	8	4	5.6	4
	8	282 + 50	N	2.6	6.7	2	0.76	8	15	35.1	4
	9	316 + 50	N	5.7	3.0	2	0.87	44	95	77.6	1
	10	318 + 60	S	3.6	5.0	2	0.74	99	26	50.2	2
	11	367 + 47	N	6.7	5.6	2	0.71	30	24	8.4	1
	12	91 + 80	S	0.3	33.0	7	0.41	36	27	5.8	4
	13	126 + 86.3	E	2.7	13.3	7	0.39	17	20	3.0	2
	14	131 + 27.8	N	1.9	14.1	7	0.70	23	40	9.8	3
	15	172 + 50	N	3.6	0.0	7	0.28	28	28	24.8	3
	16	185 + 32.2	S	3.6	10.0	7	0.39	12	18	14.5	4
	17	208 + 90.9	N	4.7	7.5	7	0.42	29	120	101.2	2
	18	243 + 19.4	N	3.7	20.3	7	0.44	18	65	45.3	3
Rim	19	331 + 72	E	2.5	18.2	1	0.79	6	45	40.7	4
Road	20	398 + 96	S	1.7	21.7	1	0.58	14	30	19.0	3
	21	450 + 05	S	5.0	19.6	1	0.67	11	28	45.4	5
	22	830 + 00	N	1.7	5.0	3	0.57	145	30	25.9	1
	23	851 + 50	W	5.2	4.0	3	0.64	60	30	298.0	1
	24	894 + 00	E	2.7	1.7	3	0.35	12	18	8.8	2
	25	934 + 50	N	5.5	0.0	3	0.55	26	47	161.0	2

TABLE I, continued

Site	No.	Station	Side Hill Exposure	% Road Gradient	% Buffer Zone Slope	Road Age (yrs)	Road Surface Area (Acre)	Watershed Area (Acre)	Sediment Flow Dist. (ft)	Sediment Volume (ft^3)	Number of Obstructions
	26	511 + 88	E	6.4	10.0	1	0.84	7	105	57.6	6
Rim	27	516 + 86	E	4.0	21.7	1	0.55	15	75	37.6	4
Road	28	531 + 26	S	7.4	12.5	1	0.16	18	35	49.4	6
cont'd	29	648 + 44	S	6.3	24.4	1	2.19	20	115	548.0	3
	30	674 + 88	S	6.7	8.3	1	0.59	23	50	105.0	3
	31	683 + 40	S	2.3	14.9	1	0.88	15	112	233.0	1
	32	705 + 90	S	3.0	20.8	1	0.82	27	33	49.2	4
	33	434 + 57.6	N	6.9	12.5	3	0.73	110	46	320.0	6
	34	428 + 00	N	4.3	12.5	3	0.61	24	86	68.6	5
State	35	398 + 01.7	E	3.1	15.9	3	0.99	28	51	40.6	3
Line	36	363 + 20	S	3.0	23.3	3	0.72	27	33	37.8	5
Road	37	331 + 90	W	4.9	13.3	3	0.71	79	13	23.3	3
	38	280 + 00	W	7.0	29.4	3	0.69	22	90	372.0	6
	39	263 + 50	W	1.0	15.9	3	0.70	73	40	68.6	4
	40	186 + 91	W	5.8	21.7	3	0.73	42	40	66.8	4
	41	179 + 50	W	2.4	22.7	3	0.54	45	150	179.0	2
	42	479 + 43	S	0.6	1.7	2	0.46	31	75	48.5	2
Hog Park	43	466 + 33	N	0.6	4.2	2	0.27	39	12	7.4	2
Reser'vr	44	433 + 50	S	3.0	13.3	2	1.04	39	33	35.1	3
Road	45	423 + 07	S	4.0	5.9	2	0.54	129	36	79.1	3
	46	403 + 80	E	1.0	3.7	2	0.32	20	53	36.4	3
	47	390 + 31	E	0.5	2.5	2	0.23	111	70	49.2	2

TABLE I, continued

Site	No.	Station	Side Hill Exposure	% Road Gradient	% Buffer Zone Slope	Road Age (yrs)	Road Surface Area (Acre)	Watershed Area (Acre)	Sediment Flow Dist. (ft)	Sediment Volume (ft^3)	Number of Obstructions
	48	880 + 09.7	S	7.1	5.0	9	0.47	7	33	47.3	2
	49	871 + 00	S	5.1	25.0	9	0.62	11	90	375.4	2
	50	836 + 16.4	N	6.3	14.7	9	0.62	20	72	161.4	1
	51	818 + 74.3	W	4.8	10.9	9	0.43	7	44	89.2	2
	52	794 + 98.8	S	4.1	28.6	9	0.55	8	50	58.8	3
Hog	53	590 + 37.7	N	0.8	9.2	7	0.37	29	72	71.9	3
Park	54	577 + 46	E	2.6	5.0	7	0.48	64	80	175.0	2
Road	55	529 + 50	N	1.4	17.5	7	0.72	9	140	106.2	3
	56	524 + 50	N	7.1	10.0	7	0.51	18	120	1330.0	4
	57	410 + 00	S	2.8	3.3	7	0.51	46	98	86.5	3
	58	334 + 82.3	W	1.0	5.8	7	0.49	25	82	417.0	3
	59	295 + 00	N	6.5	9.2	7	0.43	44	125	1200.0	5
	60	200 + 86.7	W	4.9	5.0	7	0.56	30	75	40.6	1

Chapter IV

Analysis and Results

Methods of Analysis Used

A number of analyses were made on the data shown in Table 1. Some interesting facts were obtained from reduction of just the basic field data into a useable form while other parts of the data information needed more analytical analysis. Multiple regression techniques were used to determine if relationships existed between the dependent variables and the independent variable discussed in Chapter II. For many of these variables, stepwise regression was run so that the contribution of each independent variable to the total explanation of the prediction of a given dependent variable could be evaluated.

The data collected were found to be quite variable and it was difficult to obtain correlation coefficients greater than 0.6. As a result, the data were plotted in order to obtain a better feel for the variability within the data between those variables found to correlate to some degree from the regression analysis. The plotting of the data indicated data points which were outliers which may have resulted from errors in field measurement or judgment. However, even when the outliers were removed and regression again run, the correlations were not definitive and the data still had a significant amount of variability. Several dependent variables did not contribute significantly to the variability in the explanation of the independent variables. Therefore, all of the above mentioned regression analysis was used in helping to break the

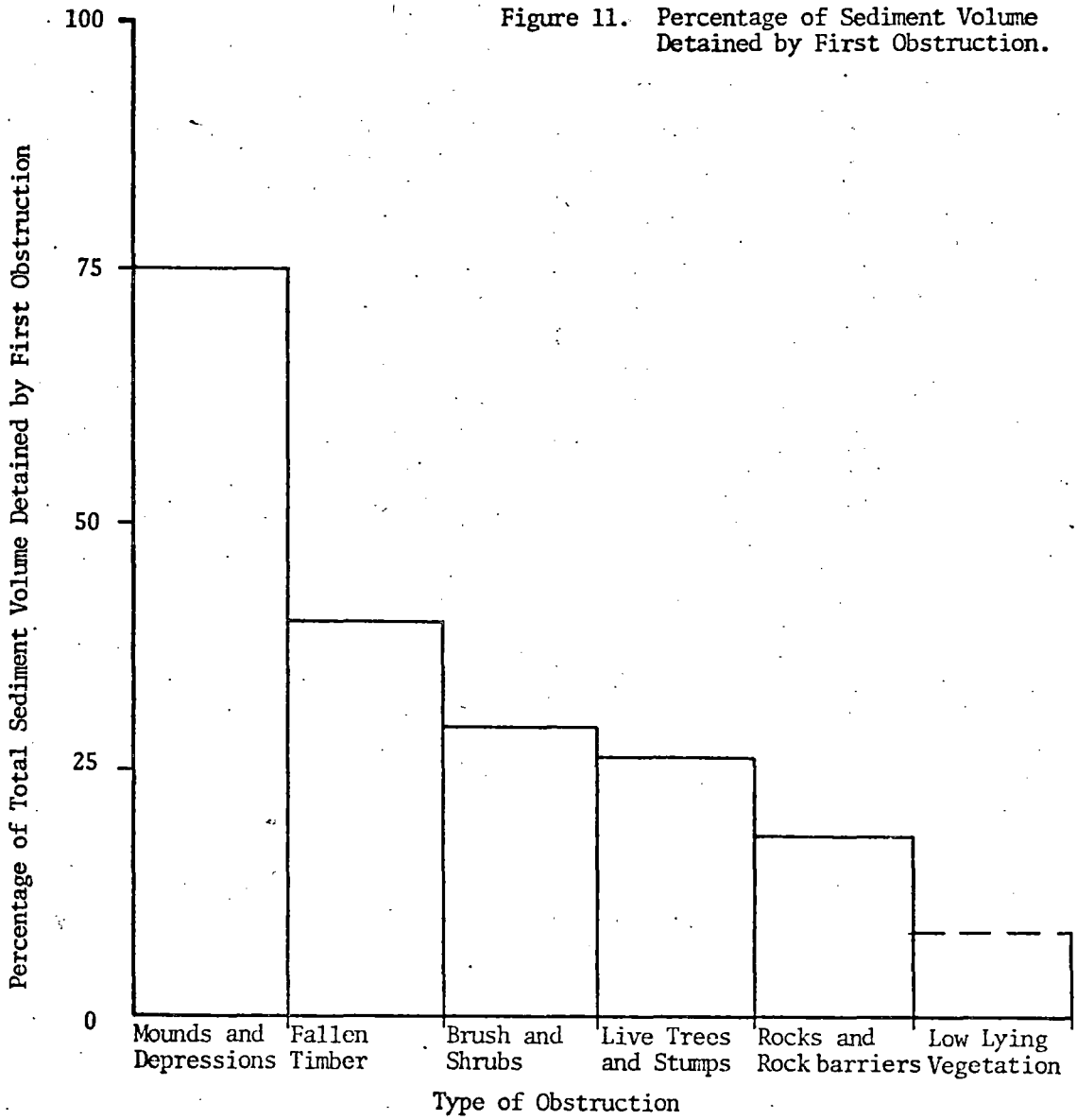
data base down into those areas where significance could be judged between a dependent variable and one or more independent variables. The stepwise regression indicated that road grade, road age, number of obstructions, and buffer zone slope contribute significantly to the description of the independent variables. The other data were not used in the following analysis.

Results of Data Analysis

One of the interesting results obtained from reduction of just the basic field data was the amount of sediment which could be detained by the use of different natural flow obstruction devices. The classification of obstruction devices (types) in order of decreasing amount detained by the first obstruction is mounds and depressions, fallen timber (logs), brush and shrubs, live trees and stumps, rocks and rock barriers, and low lying vegetation (mainly grasses). Figure 11 indicates the percentage amount of sediment detained by the first obstruction of a given type below a culvert outlet. The ordering of the different types of obstruction devices compares quite favorably with what Packer (1) found from his studies with the exception that rocks and rock barriers were interchanged with live trees and stumps in his study.

The stepwise regression analysis of all the independent variables run against each of the dependent variables produced correlation coefficients between 0.36 and 0.55. An F-test run on the data at the same time indicated that the individual data were quite variable but in some cases significant. The analysis of the results of

Figure 11. Percentage of Sediment Volume Detained by First Obstruction.



the stepwise regression of the independent variables on each of the dependent variables showed that the same independent variables were largely responsible for explaining the amount of correlation obtained with dependent variables. These independent variables were road grade, buffer zone slope, road age and in some cases number of obstructions. Road area and drainage area also appeared to have an effect but usually to a lesser degree. As a result of the regression analysis, those independent variables indicated above which had the largest affect on the dependent variables (volume of sediment and sediment flow distance) were graphically analyzed to produce useable results. The graphical analyses are presented below.

When sediment volume is plotted against road gradient for roads of different ages, an interesting result was obtained. The results of the plot using simple linear regression between accumulated sediment volume and road gradient for roads of differing age is shown in Figure 12. The following equations are the linear regression lines for each age group along with the corresponding correlation coefficient:

1 year $V = 7.76\ RGRAD + 14.88;\ R = 0.66$

2 years $V = 9.71\ RGRAD + 19.72;\ R = 0.71$

3 years $V = 41.42\ RGRAD - 36.86;\ R = 0.65$

7 years $V = 150.56\ RGRAD - 177.13;\ R = 0.69$

where:

V = accumulated sediment volume in $ft.^3$;

RGRAD = road gradient in percent; and

R = correlation coefficient.

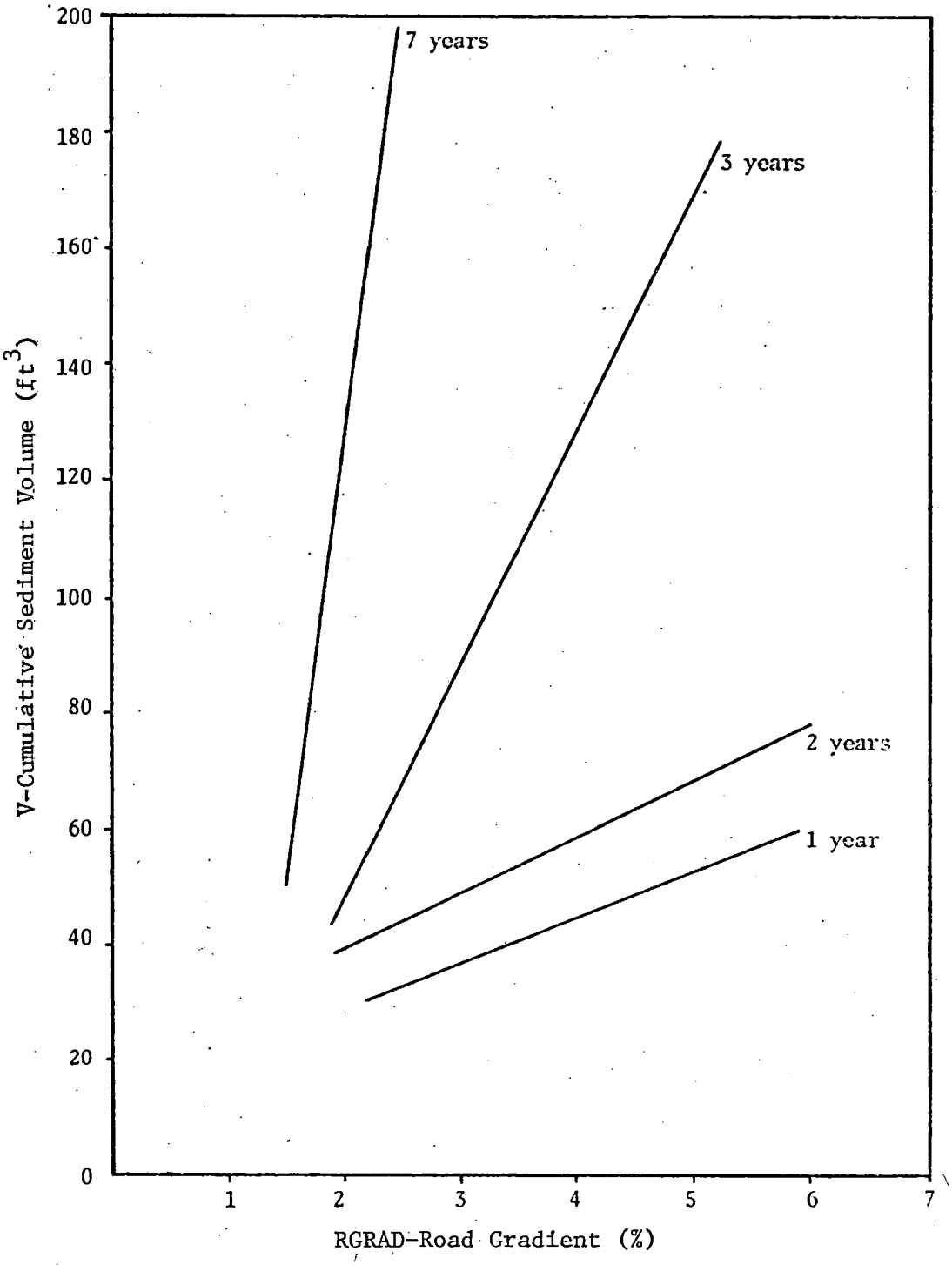


Figure 12. Relationship between road gradient and sediment volume for roads of various ages.

It is noted that there is a significant increase in sediment volume per unit increase in road gradient for the roads of the three-year age group. One possible explanation for this is the fact that the three-year old age group (the State Line Road) was constructed during a very wet runoff season and summer (1970-1972). The soils through which the State Line Road is built are very similar to the soils on the other roads in the Encampment River Study Area analyzed for sediment and therefore the amount of precipitation and snowmelt runoff is indicated as a factor in sediment volume produced. It should also be pointed out that the lines developed should not be extended beyond what is indicated on Figure 12. The lines in Figure 12 are the limits of the data and for the regression equations given for 3 and 7 years it can be seen from the slope intercepts that the data is not linear for all values of road gradient.

Another significant relationship was found between the buffer zone slope and sediment flow distance for various number of obstructions below a culvert outlet. The best fit simple linear regression lines for this combination of variables is plotted on Figure 13. Figure 13 shows that as the buffer zone steepens, the distance sediment flows downslope increases. Figure 13 also shows that as the number of downslope obstructions increases the sediment flow distance decreases for a constant buffer zone slope. The linear regression equations for various numbers of obstructions along with the corresponding correlation coefficient are:

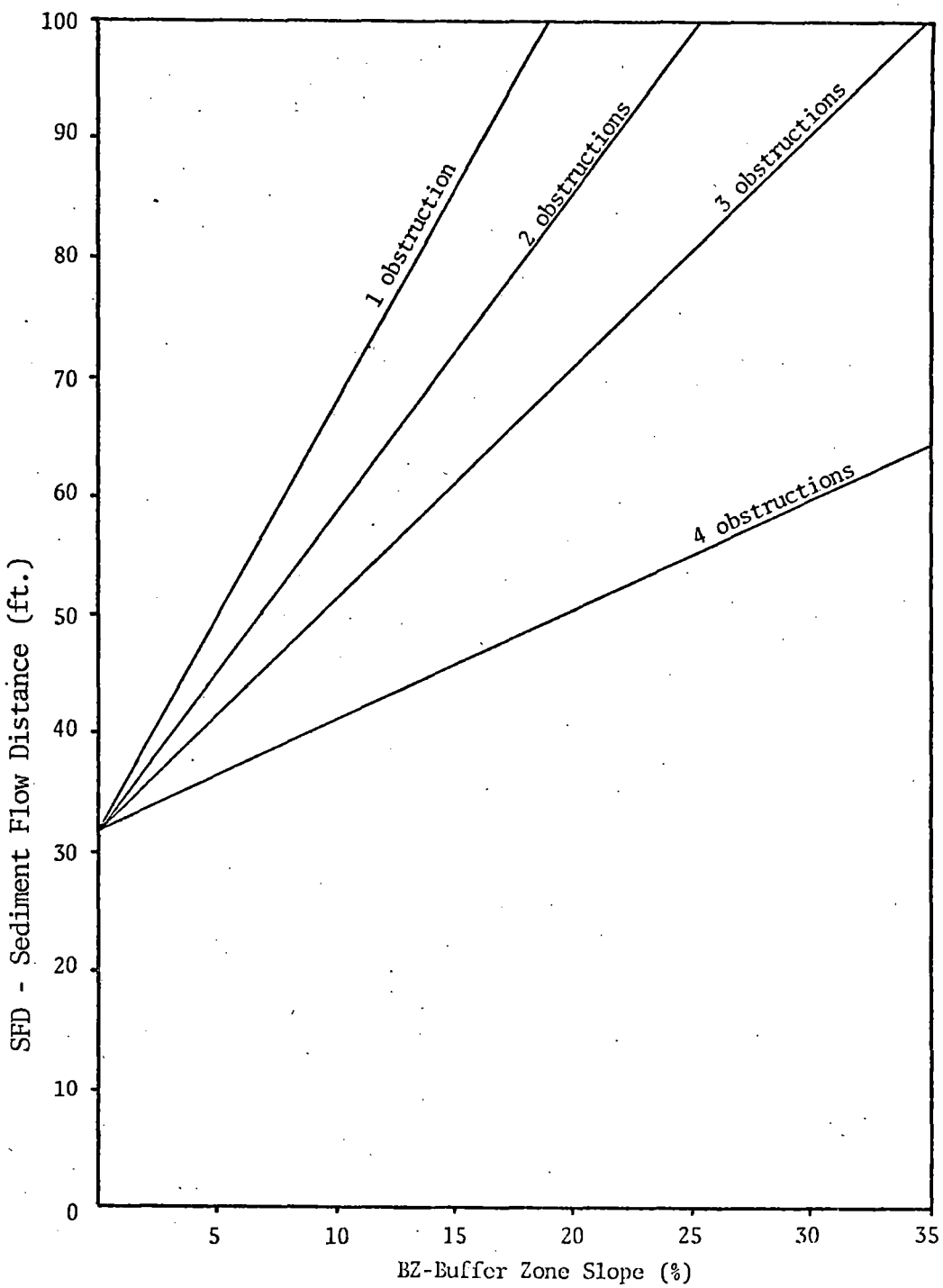


Figure 13. Relationship between buffer zone slope and sediment flow distance in feet for various numbers of obstructions.

1 obstruction SFD = 3.60 BZ + 29.35; R = 0.45

2 obstructions SFD = 2.71 BZ + 38.65; R = 0.51

3 obstructions SFD = 1.97 BZ + 44.94; R = 0.42

4 obstructions SFD = 0.93 BZ + 13.08; R = 0.66

where

SFD = sediment flow distance measured on the slope in feet;

BZ = buffer zone slope in percent; and

R = correlation coefficnet.

The y-intercept (B_o for the simple linear regression equation) of the above equations has been averaged and the lines drawn from this point for the four lines shown in Figure 13. This average intercept indicates that if the buffer zone slope is zero, the average sediment flow distance found was 31.5 feet for from one to four obstructions. The lines should not be extended for this figure (13) either outside of what is indicated on the graph which is the limits of the data base.

Chapter V

Applications and Conclusions

Application of Results

The applications of the results of this study can be applied to new as well as old roads where the possibility of eroding sediments which could possibly enter a stream exists. The method of application will utilize graphs and figures developed from this study. Two examples are given below. Most often the most effective, common, and economical obstruction to use is a downed log. The following examples will utilize downed logs as the obstructions for illustrative purposes.

Example 1. Estimation of the best obstruction placement for a new road.

Given: A culvert is located on a new road in the Sierra Madre Mountains of Wyoming with a road gradient of 2 percent above where the culvert crosses the road. The buffer zone slope immediately below the road and culvert is 10 percent. A stream parallels the road approximately 120 feet (slope distance) away from the toe of the road. The buffer zone slope is covered with a sparse growth of grass.

Required: a. the amount of sediment which will be produced in a seven-year period; b. the number of obstructions needed to provide a safety factor of 2 against sediment passing the trap area within

seven years; and c. the size of the logs needed to provide adequate sediment capacity.

Solution: Using Figure 12 with the values given above, the sediment volume produced in seven years is found to be 125 ft.^{3}. Assuming a factor of safety of 2 for sediment flow distance, the allowable sediment flow distance would be the distance from the culvert to the stream divided by the factor of safety or 120/2 which is 60 feet. By using Figure 13, the number of obstructions needed to retain the sediment within this 60 feet on a buffer zone slope of 10 percent is found to be three. It is assumed that at this location several different lengths and sizes of logs are available for use in trapping the sediment. Figures 14 and 15 give values for sediment volume retained by 10 and 15 foot long logs, respectively, placed normal to the flow direction and centered on the culvert axis for various log diameters. The distances shown are along the buffer zone slope. Similar graphs could be made for other lengths of logs or for other obstruction types (mounds and depressions, brush, etc.). Using Figure 15, a 6 inch diameter log that is 15 feet long can retain approximately 50 ft.^{3} of sediment at 20 feet downslope from the discharge end of the culvert. Therefore, three 6 inch diameter logs that are 15 feet long spaced 20 feet apart can retain 150 ft.^{3} of sediment while stopping the sediment within 60 feet of the culvert. Figure 16 shows the solution profile of Example 1.

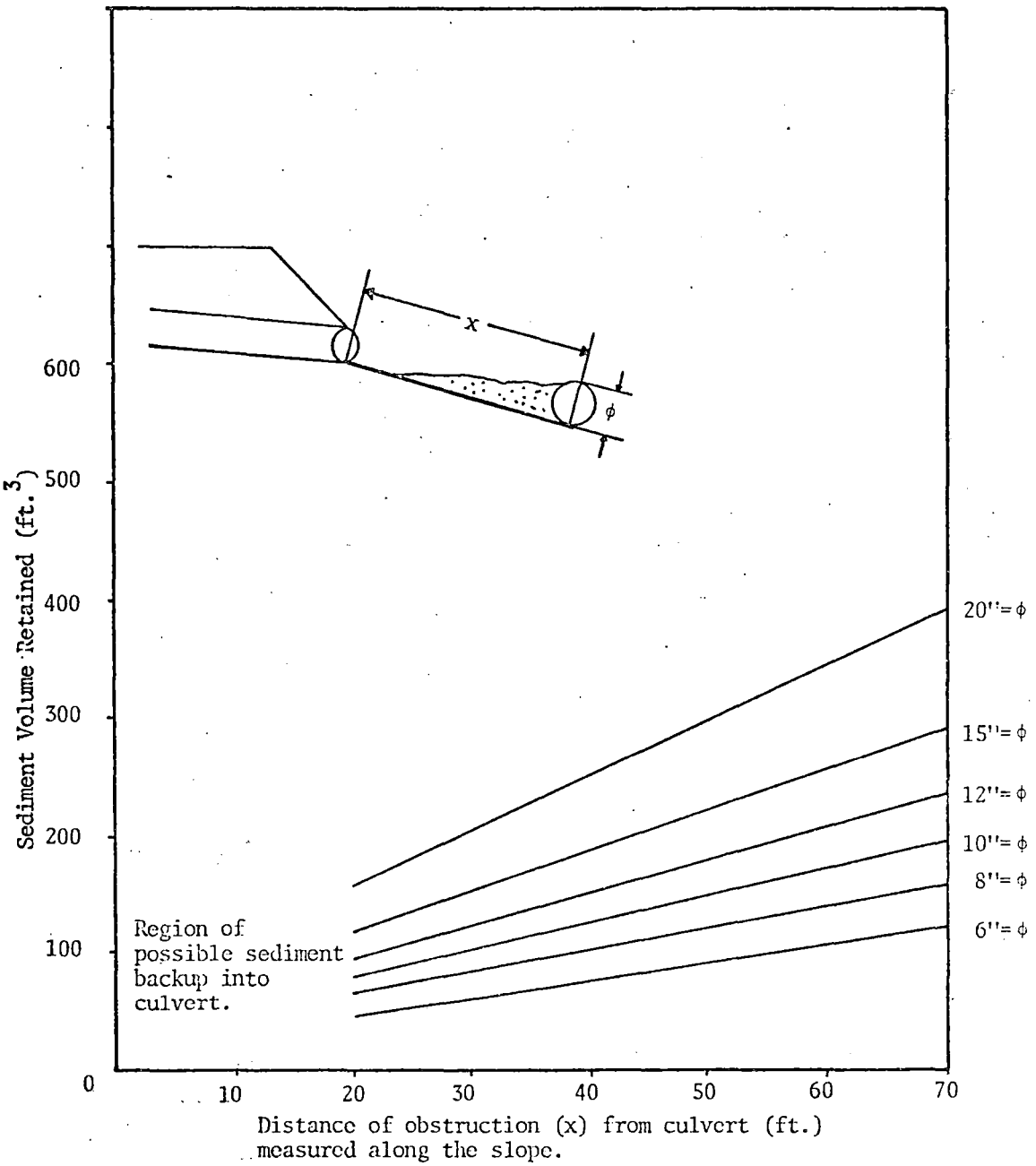


Figure 14. Sediment retention capacity of a 10 foot long log of various diameters.

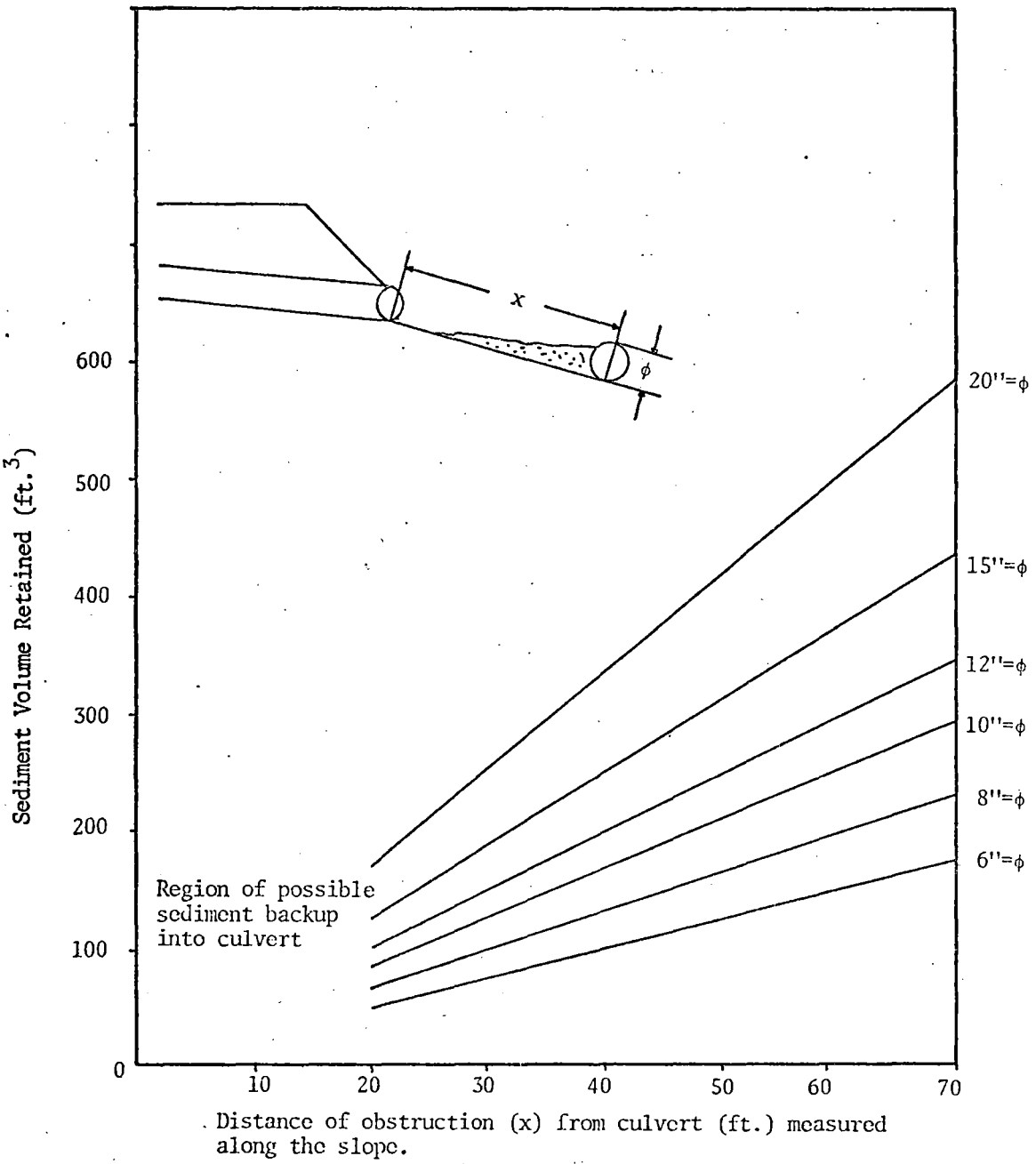


Figure 15. Sediment retention capacity of a 15 foot long log of various diameters.

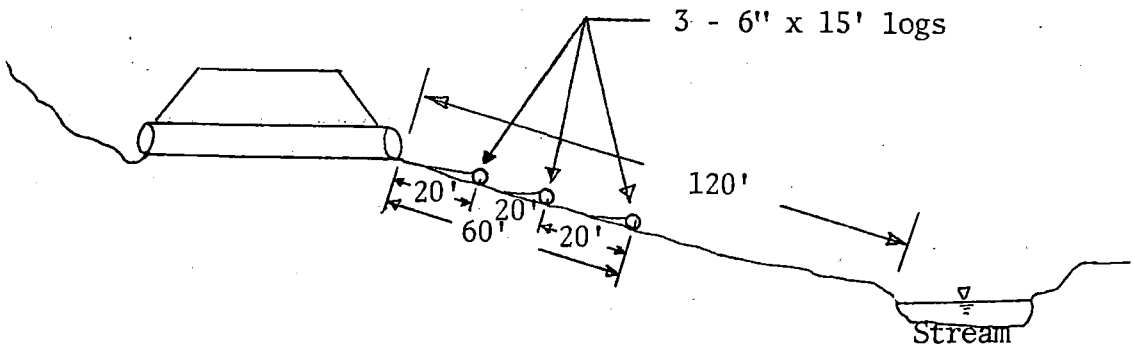


Figure 16. Profile of Solution to Example 1.

It is recommended that the first log obstruction to be placed no closer than 20 feet downslope from the discharge end of the culvert. It was found during the field investigations that obstructions placed too close to the discharge end of culverts filled the culvert itself with sediments. For protection for longer than seven years, additional logs could be placed downslope.

Example 2. Estimating obstruction placement for existing roads.

Given: A culvert is located on an existing road (three years old) with a 2 percent road gradient above where the culvert crossed the road. The buffer zone slope below the road is 5 percent. A stream parallels the road approximately 100 feet from the toe of the fill slope on the road. Heavy grass downslope from the culvert, combined with the gentle buffer zone slope, has

limited the sediment from flowing farther than 40 feet downslope.

Required: a. the amount of sediment to be produced during the next four years; b. the obstruction necessary to retain the sediment from reaching within 50 feet of the stream.

Solution: Using Figure 12, the sediment to be expected during the next four years is 79 ft.^{3} (125-46). The number of obstructions to retain this amount of sediment within a flow distance of 50 feet is one (Figure 13). From Figure 14 10' x 8" diameter log located 50 feet downslope from the culvert can retain 120 ft.^{3}, and therefore should be sufficient to retain the sediment for the next four years, combined with the dense grass. Figure 17 shows the profile of the final solution to Example 2.

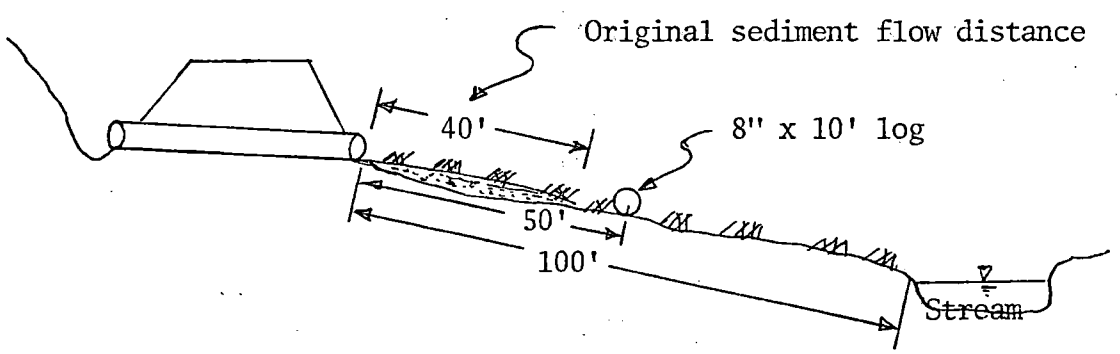


Figure 17. Profile of Solution to Example 2.

CONCLUSIONS

The results of this study brought forth a number of conclusions about the variables which affect sediment flow from roads and methods of detaining the sediment flow from reaching natural streams.

1. The major factors that contributed significant correlation to produce relationships for use in determining a method for entrapment of sediment were the road gradient, buffer zone slope, road age, number of obstructions and type of obstruction. These variables were used to estimate the volume of sediment flow distance. Other factors which were found to have some effect on sediment volume and flow but were not used in the method developed were drainage area, road area and runoff volume.
2. A method was developed for ensuring entrapment of sediments before reaching a natural stream by specifically utilizing materials found in the forest to obstruct sediment flow. The field investigations showed that natural materials such as mounds and depressions, log barriers, brush, standing trees, rocks and grass, can significantly reduce the amount of sediment which reaches a natural stream.
3. This study agreed with other studies in the ability of the first obstruction of different types of obstructions to retain sediment. The different types of obstructions studied in

retaining sediment are listed in descending order of importance: mounds and depressions, fallen timber, brush and shrubs, live trees and stumps, rocks and rock barriers, and low lying vegetation. The use of fallen timber (logs) appears to be the most economical to use as sediment entrapment barriers in most circumstances because of availability and ease of placement. Mounds and depressions should be considered whenever logs are not available.

4. The method suggested in this study to determine the number of obstructions and spacing to prevent road sediments from reaching a natural stream should be able to be applied to watersheds and roads located on granitic type soils with similar climatic conditions.

SELECTED REFERENCES

1. Packer, Paul E. "Criteria for Designing and Locating Logging Roads to Control Sediment," Forest Science, Vol. 13, No. 1, March 1967, 17 pp.

2. Leaf, Charles F. Sediment Yields from High Mountain Watersheds, Central Colorado. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station Research Paper RM-23, 1966, 15 pp.

3. Packer, Paul E. and Christensen, George F. Guides for Controlling Sediment from Secondary Logging Roads. Pocket Handbook published by Intermountain Forest and Range Experiment Station and Northern Region, U.S.D.A. Forest Service, 42 pp.

4. Ruttner, Franz, Fundamentals of Limnology. University of Toronto Press, 1952, p. 73.

5. Haupt, Harold F. and Kidd, W. Joe, Jr. "Good Logging Practices Reduce Sedimentation in Central Idaho," Journal of Forestry, Vol. 63, No. 9, September 1965, pp. 664-670.

6. Haupt, Harold F. A Method for Controlling Sediment from Logging Roads. U.S.D.A. Forest Service, and Intermountain Forest and Range Experiment Station Misc. Publication 22, 1959, 22 pp.

7. Megahan, Walter F. and Kidd, Walter J. Effect of Logging Roads on Sediment Production Rates in the Idaho Batholith. U.S.D.A. Forest Service Intermountain Forest and Range Experiment Station Research Paper INT-123, 1972, 14 pp.

8. Wiant, Ira J. Engineering Technician. U.S.D.A. Forest Service, Encampment, Wyoming. Personal correspondence dated February 20, 1976.

9. Megahan, Walter F. Deep-Rooted Plants for Erosion Control on Granitic Road Fills in the Idaho Batholith. U.S.D.A. Forest Service Intermountain Forest and Range Experiment Station Research Paper INT-161, November 1974, 18 pp.

10. Thornbury, William D. Principles of Geomorphology. Second edition, John Wiley and Sons, 1969, pp. 83-94.

11. Kissam, Phillip. Surveying. McGraw-Hill Book Company, Inc., 1956, pp. 282-285.

12. Lambe, William T. Soil Testing for Engineers. John Wiley and Sons, 1951, pp. 29-42.

13. Weast, Robert C. and Selby, Samuel M. (co-editors) Handbook of Chemistry and Physics. The Chemical Rubber Company, 48th Edition, p. A-259.

14. Draft Ecosystem Descriptions (unpublished), Medicine Bow National Forest Headquarters, U.S.D.A. Forest Service.